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## Research Joint Ventures and Technological Proximity

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# Research Joint Ventures and Technological Proximity

## Abstract

We study research joint ventures (RJV) given that knowledge spillovers depend positively on the technological proximity between firms. Possible scenarios differ in the intensity of collaboration, i.e., the (non)coordination of research activities and the extent of knowledge sharing. The investigation of bilateral RJVs in an oligopolistic market allows to distinguish effects for insider and outsider firms. Our central findings are (i) RJVs do not generally outperform competitive research with respect to innovative output, and social welfare. (ii) Technological proximity and the intensity of cooperation play a decisive role for the private and social favorability of a RJV. (iii) Joint research combined with complete knowledge sharing outperforms less intensive cooperation forms.

Keywords: research joint venture, knowledge spillovers, technological proximity, circular city

JEL Classifications: D43, L13, O31, O38

## 1. Introduction

In 2013 the Seventh Framework Program for Research and Technological Development (FP7) in the European Union (EU) expired. Its budget of 54 billion euros invested to boost research and innovation within the EU was increased to nearly 80 billion euros for the succeeding *Horizon 2020* program. Declared purpose is to strengthen international competitiveness of research and development in Europe, stimulate economic growth, and create new jobs.

Within the FP7 framework the European Commission (EC) offered various funding schemes differing in objectives and supported forms of cooperation: the most prominent among them were *collaborative projects* which focus on the creation of new knowledge and technologies.

*The Interim Evaluation of the Seventh Framework Program* (EC, 2010) identifies a considerable positive impact of the FP7 for the European Research Area (ERA). Nevertheless, despite a positive leverage effect on research and innovation efforts, network effects, and research infrastructure in the EU, some difficulties remain. For instance, during the decade 2000-2010 industry participation continuously declined: firms complained about the high administrative burden, insufficient flexibility, financial risk, and high transaction costs. Besides, firms are reluctant to participate in funded research programs whenever a large public good effect or the non-marketability of the outcome is probable. In the end it remains an open question to what extent firms would have been involved in research projects in the absence of FP7 funding.

Other empirical investigations of the European Framework Programmes draw a heterogeneous picture: while some find that public funding of research cooperations has a positive impact on the technological capability of firms (Barajas

et al., 2012), others cannot corroborate such a positive effect on the innovative output of firms (Dekker and Kleinknecht, 2008), or they even conclude that large companies' investments in research are not higher with funding than without (Fisher et al., 2009).

Economic literature has identified the internalization of knowledge spillovers as the main incentive for firms to engage in research collaborations (see, e.g. D'Aspremont and Jacquemin, 1988, Kamien et al., 1992). The question through which transmission channels knowledge actually *flows* from one firm to the other was thereby left unanswered. Recent applied spatial econometric contributions provide a sophisticated view on possible knowledge transmission channels: the spatial dimension (Jaffe, 1989) is supplemented by a-spatial forms of proximity such as institutional, technological, social, and organizational links (Boschma, 2005), where technological proximity plays the most significant role in channeling knowledge flows (Paci et al., 2014). Building on this evidence we include technological proximity of firms as the transmission channel of knowledge in our analysis of research joint ventures.

We theoretically reexamine the profitability of research collaborations by identifying incentives to coordinate research activities in the absence of public funding. Participating firms can (i) exchange knowledge with each other, (ii) coordinate research activities or (iii) agree upon both. In addition we explicitly account for the technological proximity of firms, i.e., collaboration with a technologically close or distant competitor, what varies the ability of firms to internalize knowledge spilling over from their research partner. An extensive comparison of the alternative collaboration forms provides new insights on the profitability of research joint ventures from the viewpoint of firms, consumers,

and a social planner.

The alternative intensities of collaborative research date back to Kamien et al. (1992) who extended D’Aspremont and Jacquemin (1988) to include different organizational forms of research and development (R&D) collaborations. Either all firms or none participate(s) in the research cooperation, i.e., Kamien et al. (1992) do not consider the possibility that only some firms in a market join a RJV. Anbarci et al. (2002) analyze the effect of R&D complementarities for two alternative collaboration forms: independent R&D and non-cooperative R&D with perfect knowledge spillovers but uncoordinated research. In contrast to Kamien et al. (1992) they find that non-cooperative R&D may dominate independent R&D with respect to R&D output, profits, and welfare. Brod and Shivakumar (1997) show that cooperative R&D is preferred to non-cooperative R&D by firms and consumers irrespective of (non)collusive behavior on the product market. However, they note the importance of investigating partial cooperation, since industry-wide agreements may be instable. Disregarding inter-firm knowledge spillovers, Ferrett and Poyago-Theotoky (2012) allow for such partial cooperation, but their focus is the choice of firms between a RJV and a merger.

This paper extends the existing literature in two ways (i) by analyzing partial cooperation resulting in insider and outsider firms, and (ii) by including technological proximity of firms as transmission channel of knowledge spillovers. We contribute new insights on the private and social profitability of alternative research collaboration forms.

The remainder of the paper is organized as follows. Section 2 introduces the benchmark model where firms independently choose R&D expenditure. Section 3 presents the three different R&D collaboration scenarios and respective

equilibrium solutions. Section 4 compares these scenarios from the viewpoint of firms, consumers, and a social planner. Section 5 concludes. All analytical proofs can be found in the Appendix.

## 2. The benchmark model

Consider an oligopoly where  $n$  firms produce and sell a single product in a horizontally differentiated product market. Following the principle of maximum differentiation firms are evenly distributed across a circle with unit circumference. The position of firm  $i$  is given by  $y_i \in [0, 1]$  and the distance between two firms reflects the degree of differentiation between their products. A continuum of consumers is uniformly distributed on the circle with unit density and a mass normalized to one where location  $y_\theta$  reflects the individual preference of consumer  $\theta$ .

Firms compete in a two-stage game: in the first stage they either cooperatively or independently set their R&D investment level and in the second stage they compete in prices, regardless of possible research alliances in the first stage. The incentives to form a RJV are driven by two countervailing forces which are asymmetric across firms: *enabling spillovers* and *absorptive capacity*. While the latter captures a firm's ability to use knowledge received via spillovers, i.e., the firm is a knowledge-taker, enabling spillovers unintentionally leave the firm, i.e., the firm is a knowledge-giver. Kamien and Zang (2000) analyze absorptive capacity in the context of RJVs: by choosing either a narrow or a broad research approach firms endogenously influence the spillovers they generate and at the same time develop their capability to absorb the spillovers they receive. Building on this approach we assume that the technological distance between firms

drives their respective absorptive capacity. Empirical studies confirm a positive and significant impact of technological proximity on knowledge spillovers (Paci et al., 2014) whereas the absorptive capacity of a firm is found to decrease with technological distance (Nooteboom et al., 2007). Following these findings we use the respective distance between firms on the circle as a proxy for the technological distance between firms. This argument especially holds for the chosen context of process innovations where research projects are closely related to a product's properties meaning that the closer products are located to each other, i.e., the less differentiated they are, the closer related is the research targeting an improvement of the respective production process. Proximity in product space thus implies a high mutual absorptive capacity of unintended knowledge spillovers.

Firms face constant and identical marginal costs  $c$  which can be reduced by investing in R&D. In addition, marginal costs to some extent are reduced due to the involuntary knowledge spillovers from competitors. The spillovers firm  $i$  receives from its competitor  $j$  are given by

$$\beta_{i,j} = (1 - \delta_{i,j})x_j \quad (1)$$

where  $x_j$  is firm  $j$ 's research expenditure and  $\delta_{i,j}$  is the technological distance between firms  $i$  and  $j$ ,  $\delta_{i,j} \in [0, \frac{n-1+\kappa}{2n}]$ , where  $\kappa = 1$  for  $n$  even,  $\kappa = 0$  for  $n$  odd. Spillovers increase in the level of R&D investments,  $x_j$ , and decrease in the technological distance between firms  $i$  and  $j$ ,  $\delta_{i,j}$ . Effective R&D investments of firm  $i$  are given by its individual R&D effort plus the knowledge spillovers firm  $i$  receives from its  $(n - 1)$  competitors

$$X_i = x_i + \sum_{j \neq i}^n (1 - \delta_{i,j})x_j. \quad (2)$$

These effective R&D investments reduce marginal costs according to  $c_i = c - X_i$ . In this simple setup R&D effort  $x_i$  corresponds to R&D output. R&D effort comes at costs

$$C(x_i) = \frac{1}{2}\gamma x_i^2, \quad (3)$$

and thus has diminishing marginal returns. The inverse of parameter  $\gamma$  captures the technological productivity in the respective market: the higher  $\gamma$ , the less efficient firms are in producing R&D outcome.

Firms compete in prices only with their direct neighbors to the left ( $i - 1$ ) and right ( $i + 1$ ) on the product market. Every consumer  $\theta$  buys one good. As not every possible variant of the good is offered, not all consumers' preferences are satisfied meaning that some consumers suffer a utility loss,  $t(|y_\theta - y_i|)$ , where parameter  $t$  reflects the extent to which a deviation from the individual preference  $y_\theta$  reduces utility. While a high value of  $t$  reflects inflexible consumers facing a high utility loss, a low value of  $t$  represents consumers for which a mismatch between offered and preferred good only leads to a minor utility reduction. Individual utility for consumer  $\theta$  can be specified as

$$U_\theta = v - p_i - t(|y_\theta - y_i|) \quad (4)$$

where  $v$  is the reservation price and  $p_i$  is the price for the product sold by firm  $i$  located at  $y_i$ . Consumers buy one unit of the good that maximizes utility. Identifying the consumer indifferent between two neighboring firms determines the demand function of firm  $i$  as

$$D_i = \frac{2t/n + p_{i+1} + p_{i-1} - 2p_i}{2t}. \quad (5)$$

Whenever the price of one of the neighboring firms increases, firm  $i$ 's demand



increases because some consumers shift away from the (more expensive product of the) rival firm.

In the considered two stage game firms choose R&D expenditure and subsequently prices to maximize their profits given by

$$\Pi_i = (p_i - c + X_i)D_i - \frac{1}{2}\gamma x_i^2. \quad (6)$$

To identify the subgame perfect Nash equilibrium, we solve the game by backward induction.

#### *Stage 2: Product market competition*

In the second stage each firm maximizes profits  $\Pi_i$  by choosing prices  $p_i$  taking R&D investments as given. Solving the first order condition<sup>1</sup>

$$p_i = \frac{2t/n + 2c + p_{i+1} + p_{i-1} - 2X_i}{4} \quad (7)$$

for  $p_i$  yields optimal prices given effective R&D expenditure

$$\hat{p}_i = t/n + c + \frac{-\sum_{j=0}^{K+\kappa} b^{K+\kappa-j} X_{i+j} - \sum_{j=1}^K b^{K+\kappa-j} X_{i-j}}{2b^{K+\kappa} - b^{K+\kappa-1}} \quad (8)$$

where  $K \equiv (n-1-\kappa)/2$  and  $b^K \equiv 4b^{K-1} - b^{K-2}$  with  $b^0 \equiv 1$  and  $b^{-1} \equiv 1+\kappa$ .

It is easy to show that prices decrease in R&D expenditure. While the effect of own R&D expenditure on price  $p_i$  is stronger than the effect of rivals' R&D expenditure on  $\hat{p}_i$ , the latter effect becomes even weaker, the more distant a rival firm is.<sup>2</sup>

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<sup>1</sup>The second order condition (SOC) holds, since  $\partial^2 \Pi_i / \partial p_i^2 = -4 < 0$ .

<sup>2</sup>Obviously  $\partial \hat{p}_i / \partial x_i = \partial \hat{p}_i / \partial X_i \partial X_i / \partial x_i < 0$ . As  $b^K > b^{K-1} > \dots > b^0 > 0$  we have  $|\partial \hat{p}_i / \partial X_i = b^K| > |\partial \hat{p}_i / \partial X_{i\pm j} = b^{K-j}|$  where  $\partial \hat{p}_i / \partial X_i = b^K > \partial \hat{p}_i / \partial X_{i\pm 1} = b^{K-1} > \partial \hat{p}_i / \partial X_{i\pm 2} = b^{K-2} > \dots$ .

Equilibrium demand is given by

$$\hat{D}_i = \frac{1}{n} + \frac{(b^{K+\kappa} - b^{K+\kappa-1})X_i - \sum_{j=1}^{K+\kappa} b^{K+\kappa-j}X_{i+j} - \sum_{j=1}^K b^{K+\kappa-j}X_{i-j}}{(2b^{K+\kappa} - b^{K+\kappa-1})t}. \quad (9)$$

It is straightforward to identify a general relation between effective R&D investments, prices and demand: whichever firm has the highest effective R&D investments sets the lowest product price and therefore realizes the highest market share.<sup>3</sup> Anticipating optimal price choices the reduced form profits on the second stage are given by

$$\Pi_i = \hat{D}_i^2 t - C(x_i). \quad (10)$$

#### *Stage 1: R&D investments*

In the first stage of the game firms decide on optimal R&D expenditure given price decisions in stage two. Firms receive and create knowledge spillovers according to the technological distance between them as specified in equation (1). The scenario where firms do not collaborate, i.e., undertake their own research projects and maximize individual profits, research competition (C), serves as our benchmark. Maximizing

$$\Pi_i^C = (\hat{p}_i(x_i) - c_i(x_i))\hat{D}_i(x_i) - C(x_i) \quad (11)$$

gives us firm  $i$ 's optimal R&D investment.<sup>4</sup> Due to the fact that firms ex-ante face the same costs of producing,  $c$ , the first order conditions yield

$$\hat{x}^C = \frac{2 \left[ b^{K+\kappa} - b^{K+\kappa-1} - 2 \sum_{j=1}^K (1 - j/n) b^{K+\kappa-j} \right]}{(2b^{K+\kappa} - b^{K+\kappa-1})n\gamma} \quad \forall i = 1, \dots, n. \quad (12)$$

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<sup>3</sup>As parameters  $t$  and  $c$  are constant and  $b^K > b^{K-1} > \dots > b^0 > 0$  it can easily be verified that whenever firm  $i$  has the higher R&D expenditure,  $X_i > X_{i \pm j}$  for  $j = 1, \dots, K$ , prices are lowest and demand is highest for this firm.

<sup>4</sup>The SOC requires  $\gamma > \frac{2 \left[ b^{K+\kappa} - b^{K+\kappa-1} - 2 \sum_{j=1}^K (1 - j/n) b^{K+\kappa-j} \right]^2}{(2b^{K+\kappa} - b^{K+\kappa-1})^2 t}$ .

The efficiency parameter  $\gamma$  and the number of participating firms  $n$  drive optimal R&D investments. The lower  $\gamma$  (the more efficient the R&D process) the higher the R&D expenditure of a firm,  $\partial \hat{x}^C / \partial \gamma < 0$ .

Given optimal R&D expenditure, equilibrium profits<sup>5</sup> in the case of research competition amount to

$$\hat{\Pi}^C = t/n^2 - \frac{1}{2}\gamma(\hat{x}^C)^2. \quad (13)$$

### 3. Research collaboration

The effects of different collaboration intensities for the (non-) participants of a RJV can be sufficiently analyzed in a setting with five firms and one possible bilateral cooperation.<sup>6</sup> This yields two possible constellations: two close competitors cooperate their research activities forming a *close RJV* or two distant competitors participate in a research alliance forming a *distant RJV*. Figure 1 illustrates the case of a close RJV between firms 1 and 2 (in) where two adjacent outsiders (ad) are direct neighbors to one of the insiders and firm 4 is nonadjacent (nonad) to either insider. In the distant RJV between firms 1 and 3 as depicted in figure 2 two adjacent firms are direct neighbors to one of the insiders and one outsider is encompassed (enc) by two insiders.

Cooperating firms choose the degree of their research collaboration by form-

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<sup>5</sup>To assure that  $\hat{\Pi}^C \geq 0$ ,  $\gamma \geq \frac{2 \left[ b^{K+\kappa} - b^{K+\kappa-1} - 2 \sum_{j=1}^K (1-j/n) b^{K+\kappa-j} \right]^2}{(2b^{K+\kappa} - b^{K+\kappa-1})^2 t}$  needs to be fulfilled. As the critical threshold corresponds to the SOC for R&D expenditure, this is always the case.

<sup>6</sup> $n = 5$  combined with the possibility of bilateral cooperation constitutes the simplest but sufficient setting allowing us to derive results for a close and a distant RJV distinguishing two types of outsider firms as specified below.

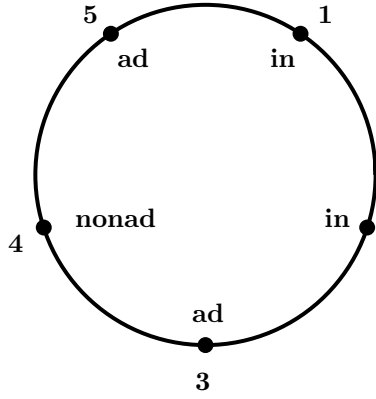


Figure 1: close RJV

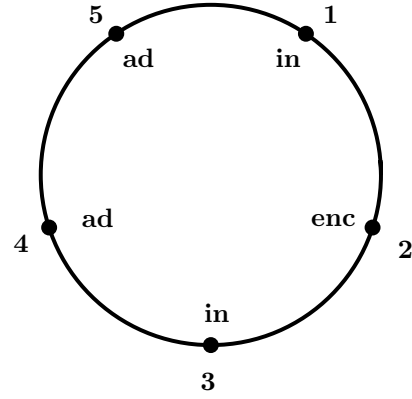


Figure 2: distant RJV

ing a (i) knowledge creation alliance, (ii) knowledge exchange alliance, or a (iii) knowledge creation and exchange alliance. The least intensive cooperation takes place in a research alliance where partners coordinate research activities but do not share knowledge and experiences with each other. We denote this type of cooperation as a *Knowledge Creation Alliance (KC)* where partners coordinate their research activities  $x_r$  while absorptive capacity and enabling spillovers remain unaffected by the cooperation. Since collaborating firms coordinate their research activities they maximize joint profits internalizing the knowledge spillovers to the partner. All outsider firms continue to maximize their individual profits.

Contrasting this joint production of knowledge a *Knowledge Exchange Alliance (KE)* refers to pure knowledge exchange, e.g., through cross-licensing agreements. Participating firms individually invest in research choosing  $x_i$  and  $x_j$  separately, but share R&D outcome. Thus, the technological distance between the firms in the KE diminishes ( $\delta_{i,j} = 0$ ) meaning that enabling spillovers increase to their maximum. Additionally insiders exchange the knowledge they

receive via spillovers from outsiders. Consequently, knowledge spillovers from outsider firms are the same for both insiders, where technological distance corresponds to the lowest distance between an outsider firm and any insider firm. An example is provided in figure 3. Suppose firms independently invest in research (C). The knowledge spillovers firm 5 creates and firm 2 absorbs are then given by  $\beta_{2,5}^C = (3/5)x_5$  as the underlying technological distance is  $\delta_{2,5} = 2/5$  (indicated by the dotted arrow from point 5 to 2) and  $\beta_{2,5} = (1 - \delta_{5,2})x_5$  as specified in equation (1). In a scenario with a close KE between firms 1 and 2, the technological distance between firms 5 and 2 decreases as the technological distance to outsider firms now corresponds to the lowest distance between any insider and the outsider. In our example case this lowest distance to the outsider firm 5 is between insider firm 1 and firm 5. Thus, the technological distance between firms 5 and 2 decreases from  $\delta_{2,5}$  to  $\delta_{1,5}$  (dashed arrow in figure 3). Consequently, absorbed knowledge spillovers increase to  $\beta_{2,5}^{KE} = (4/5)x_5$ .

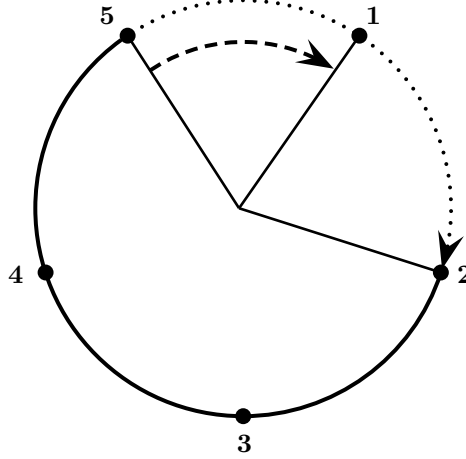


Figure 3: Knowledge spillovers, close KE between firms 1 and 2

The same argumentation holds for outsider firms as from their viewpoint

collaborating firms act as a single entity. Technological distance between the close KE and an outsider corresponds to the distance between the respective outsider and the insider nearest to him. Table 1 summarizes the changes in knowledge spillovers when moving from research competition (C) to a close (\*) or a distant (+) Knowledge Exchange Alliance. The situation illustrated in our example (figure 3) is situated in the second row, last column: in scenario C firm 2 receives spillovers of  $(3/5)x_5$ , whereas for a close KE between firms 1 and 2 it receives  $(4/5)x_5$ .

emitter \ recipient	firm 1 *, +	firm 2 *	firm 3 +	firm 4	firm 5
firm 1 *, +		$4/5, 1^*, 4/5^+$	$3/5, 4/5^*, 1^+$	$3/5, 3/5^*, 4/5^+$	$4/5, 4/5^*, 4/5^+$
firm 2 *	$4/5, 1^*, 4/5^+$		$4/5, 4/5^*, 4/5^+$	$3/5, 3/5^*, 3/5^+$	$3/5, 4/5^*, 4/5^+$
firm 3 +	$3/5, 4/5^*, 1^+$	$4/5, 4/5^*, 4/5^+$		$4/5, 4/5^*, 4/5^+$	$3/5, 3/5^*, 4/5^+$
firm 4	$3/5, 3/5^*, 4/5^+$	$3/5, 3/5^*, 3/5^+$	$4/5, 4/5^*, 4/5^+$		$4/5, 4/5^*, 4/5^+$
firm 5	$4/5, 4/5^*, 4/5^+$	$4/5, 4/5^*, 3/5^+$	$3/5, 3/5^*, 4/5^+$	$3/5, 4/5^*, 4/5^+$	

Table 1: Knowledge spillovers for (C), close RJV\* (between firms 1 and 2) and distant RJV+ (between firms 1 and 3) for KE and KCE

Since a KE is a pure knowledge exchange alliance, firms maximize individual profits. Participating firms thus face a trade-off: on the one hand a joint venture increases their absorptive capacity to a maximum, on the other hand increasing spillovers benefit outsider firms.

A *Knowledge Creation and Exchange Alliance (KCE)* is the most intensive

collaboration: partners fully share R&D results and jointly choose their R&D expenditure. Thus, spillovers change to the same extent as when moving from research competition (C) to a close or distant KE but additionally firms in a KCE coordinate their R&D activities.

Table 2 summarizes the different cooperation forms where the intensity of collaboration increases from top to bottom.<sup>7</sup>

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<sup>7</sup>The scenarios correspond to those analyzed in Kamien et al. (1992): (C)  $\hat{=}$  R&D Competition, (KE)  $\hat{=}$  RJV Competition, (KC)  $\hat{=}$  R&D Cartelization, (KCE)  $\hat{=}$  RJV Cartelization.

Scenario	R&D expenditure and spillovers
R&D Competition (C)	<ul style="list-style-type: none"> <li>· firms compete in R&amp;D separately choosing <math>x_i</math> and <math>x_j</math></li> <li>· spillovers decline with the technological distance between firms, <math>\beta_{ij}^C = (1 - \delta_{i,j})x_j</math></li> <li>· individual profit maximization</li> </ul>
Knowledge Creation Alliance (KC)	<ul style="list-style-type: none"> <li>· participating firms jointly create knowledge <math>x_r</math></li> <li>· spillovers decline with the technological distance between firms, <math>\beta_{ij}^{KC} = (1 - \delta_{i,j})x_j</math></li> <li>· joint profit maximization of insiders</li> </ul>
Knowledge Exchange Alliance (KE)	<ul style="list-style-type: none"> <li>· participating firms separately choose <math>x_i</math> and <math>x_j</math> but exchange created knowledge <math>x_i</math> and <math>x_j</math></li> <li>· maximal spillovers between insiders, <math>\beta_{ij}^{KE} = x_j</math></li> <li>· individual profit maximization</li> </ul>
Knowledge Creation and Exchange Alliance (KCE)	<ul style="list-style-type: none"> <li>· participating firms jointly create and exchange knowledge <math>x_r</math></li> <li>· maximal spillovers between insiders, <math>\beta_{ij}^{KCE} = x_j</math></li> <li>· joint profit maximization of insiders</li> </ul>

Table 2: Overview of possible research cooperations between firms  $i$  and  $j$

In the following we present the equilibrium results for the different collaboration forms comparing the results for insiders and outsiders, and close versus distant cooperations. In all scenarios firms simultaneously choose R&D expenditure. Whenever firms jointly create new knowledge, which is the case for KC and KCE, they maximize joint profits,  $\Pi_{joint} = \Pi_i + \Pi_j$  with respect to their



common R&D expenditure  $x_r$ , where  $\Pi_i$  and  $\Pi_j$  are the reduced form profits given by equation (6). Given that firms conduct research individually, as is the case for C and KE, firms maximize individual profits  $\Pi_i$  with respect to R&D expenditure  $x_i$ . Optimization leads to the Nash equilibrium regarding optimal R&D investment. Forward calculations then yield equilibrium prices, firm demand and profits for each scenario. Detailed derivations of the analytical results are given in Appendix A (for a KC), Appendix B (for a KE) and Appendix C (for a KCE).

### 3.1. Knowledge Creation Alliance (KC)

In a KC firms coordinate research activities but do not exchange knowledge. Table 3 summarizes equilibrium results regarding R&D expenditure, effective R&D investments, and profits for a close and a distant KC. Note that the ordering of equilibrium values is valid irrespective of R&D efficiency  $\gamma^8$ . Comparing R&D investments of insiders and outsiders, we find that insiders in a close (distant) KC invest more (less) in R&D than outsiders. With a KC participating firms maximize joint profits and thereby internalize the effect of knowledge spilling out to the respective research partner what positively affects their R&D expenditure. At the same time a countervailing mechanism is at work: insiders anticipate that they create knowledge spillovers benefiting outsiders and therefore decrease their R&D expenditure. While for a close KC the latter effect is overcompensated by the internalization of spillovers, in a distant KC anticipating the positive effect for outsiders leads to lower R&D investments. As a consequence insider profits are higher than outsider profits

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<sup>8</sup>Analytical results are given in Appendix A.

in a close KC, whereas in a distant KC profits of insiders are not the highest in the market. Since receiving and emitting knowledge spillovers are the same for every firm in a KC, effective R&D investments only depend on own and the rival's level of R&D expenditure. In a close KC insider firms invest more in R&D than outsiders whereas both benefit from high incoming knowledge spillovers. Since the high effective R&D investments are correlated with a high demand (see footnote 2), profits are highest for insiders. In a distant KC R&D investments of insiders are lower than those of outsiders. An encompassed firm suffers from such investment strategies, whereas adjacent firms at least profit from higher incoming knowledge spillovers what leads to higher effective R&D investments and profits for adjacent outsiders.

Comparing R&D investments in a close versus a distant KC we find that firms invest less in the latter case. If two technologically distant firms coordinate R&D expenditure but do not exchange knowledge they reduce R&D investments to save costs. While they benefit from higher knowledge spillovers due to a lower technological distance to outsiders, outsiders also profit from increasing spillovers. If two technologically close firms form a KC, it is profitable for them to agree on high R&D investments as involuntary knowledge spillovers to rival firms do not increase as strong as in a distant KC. Comparing profits in either case nevertheless shows that it is more profitable to cooperate with a technologically distant partner and agree on a low level of R&D expenditure to save costs. As additionally insiders of a distant KC can raise prices due to non-neighboring markets, profits are higher in a distant than in a close KC.

	close RJV		distant RJV
$x_i$	$x_{in} > x_{out}$		$x_{in} < x_{out}$
$X_i$	$X_{in} > X_{ad} > X_{nonad}$		$X_{ad} > X_{in} > X_{enc}$
$\Pi_i$	$\Pi_{in} > \Pi_{ad} > \Pi_{nonad}$		$\Pi_{ad} > \Pi_{in} > \Pi_{enc}$
$x_{in}$	$x_{in}^{close}$	$>$	$x_{in}^{dist}$
$\Pi_{in}$	$\Pi_{in}^{close}$	$<$	$\Pi_{in}^{dist}$

Table 3: Equilibrium outcomes for a KC

### 3.2. Knowledge Exchange Alliance (KE)

If firms form a KE they exchange knowledge, but do not coordinate their research activities. Table 4 summarizes equilibrium results regarding R&D expenditure, effective R&D investments, and profits for a close and a distant KE. In this scenario equilibrium values crucially depend on R&D efficiency  $\gamma$ : the more complex and costly the R&D process, the less insiders invest in R&D. Equilibrium R&D expenditure subject to  $\gamma$  is depicted in figure 4 (figure 5) for a close (distant) KE. Obviously firms in a close (distant) KE invest more in R&D only if  $\gamma < \bar{\gamma}_r$  ( $\gamma < \bar{\bar{\gamma}}_r$ ), with  $r = \{\text{close, dist}\}$ .<sup>9</sup> Recall that with a KE firms independently maximize profits—spillovers to their research partner are thus not internalized, what results in a free-rider problem. If R&D is highly efficient and thus relatively cheap (low  $\gamma$ ), insiders choose high R&D investments accepting the consequence of higher knowledge spillovers to rivals. If technological efficiency is low (high level of  $\gamma$ ), insider invest less in R&D than outsider as the free-rider problem exceeds the cost saving effect.

<sup>9</sup>For the definitions of  $\bar{\gamma}_r$  and  $\bar{\bar{\gamma}}_r$  see Appendix B.

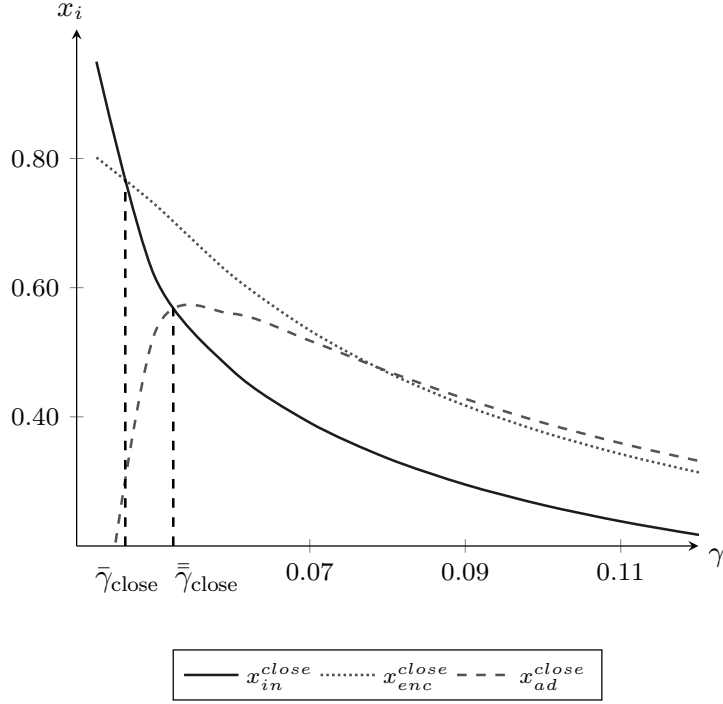


Figure 4: R&D expenditure in a close KE

Nonetheless insider realize higher profits than outsider as—due to high incoming knowledge spillovers—insider have the highest effective R&D investments in the market, regardless of  $\gamma$ . Therefore they are able to set the lowest market prices attracting the largest share of consumers. In addition, for  $\gamma < \bar{\bar{\gamma}}_r$ , with  $r = \{\text{close, dist}\}$ , insider firms have the lowest R&D costs as R&D investments are lower than those of outsiders. Combined with the higher demand insider realize higher profits than outsiders and thus always prefer to be part of a KE.

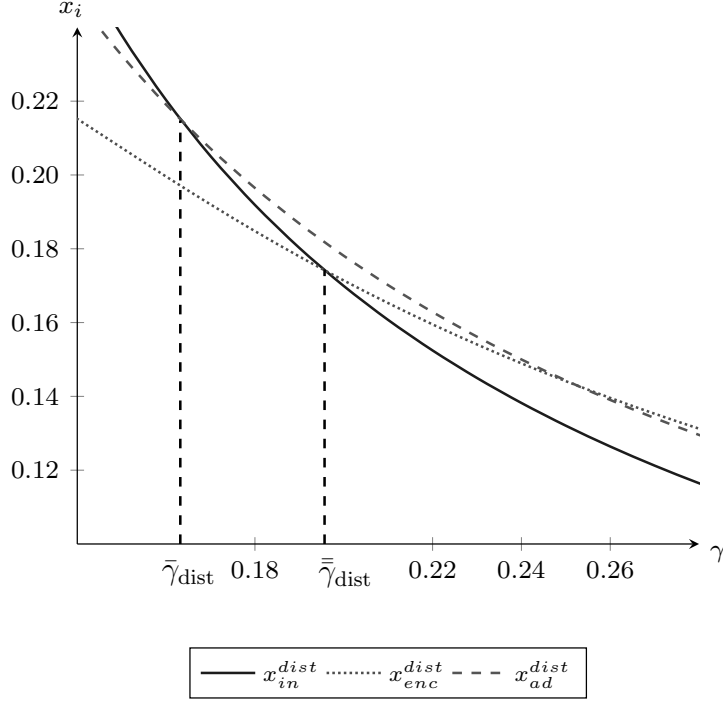


Figure 5: R&D expenditure, in a distant KE

Comparing R&D investments in a close versus a distant KE we find that insiders invest more in the latter scenario. Note that spillovers between insider firms are maximal irrespective of the technological distance. At the same time spillovers to outsiders are lower in a distant than in a close KE (see Table 1) what makes the free-rider problem less severe in distant cooperations. Consequently R&D expenditure is higher in a distant KE. We show in Appendix B that profits are also higher in this scenario, mainly due to two reasons: first, the gains from exchanging knowledge are higher if the research partner is technologically distant (see Table 1), and second, insiders are able to erode a higher market share from rivals in a distant KE because they can cut off demand from all three outside firms (see figures 1 and 2). Therefore firms prefer a distant over a close KE.

	close RJV		distant RJV
$x_i$	for $\gamma < \bar{\gamma}_{\text{close}}$ we have $x_{in} > x_{out}$		for $\gamma < \bar{\gamma}_{\text{dist}}$ we have $x_{in} > x_{out}$
	for $\gamma > \bar{\gamma}_{\text{close}}$ we have $x_{in} < x_{out}$		for $\gamma > \bar{\gamma}_{\text{dist}}$ we have $x_{in} < x_{out}$
$X_i$	$X_{in} > X_{ad} > X_{nonad}$		$X_{in} > X_{ad} > X_{enc}$
$\Pi_i$	$\Pi_{in} > \Pi_{ad} > \Pi_{nonad}$		$\Pi_{in} > \Pi_{ad} > \Pi_{enc}$
$x_{in}$	$x_{in}^{close}$	$<$	$x_{in}^{dist}$
$\Pi_{in}$	$\Pi_{in}^{close}$	$<$	$\Pi_{in}^{dist}$

Table 4: Equilibrium outcomes for a KE

### 3.3. Knowledge Creation and Exchange Alliance (KCE)

A KCE is the most intensive research collaboration between two firms: joint research is accompanied by the exchange of knowledge with their partner. Table 5 summarizes the equilibrium results for this cooperation form.<sup>10</sup> For both, close and distant cooperation, insiders choose higher R&D expenditure than outsiders,  $x_{in} > x_{out}$ . Due to the joint maximization of profits, firms take the positive externality of own research investments on their partner into account and thus overcome the free-rider problem. Therefore firms participating in a close or distant KCE gain the highest profits in the market. As spillovers between insiders and their R&D expenditure are maximal, they have the highest effective R&D investments. Consequently they set the lowest product prices and attract the highest market share (see footnote 2).

If insiders are technologically distant research partners they can absorb relatively more additional R&D knowledge from each other (see Table 1). Therefore the positive externality of R&D investments on the partner's profit is stronger

<sup>10</sup> Analytical results are given in Appendix C.

and thus R&D expenditure is higher in a distant than in a close KCE. Although R&D costs are higher in a distant KCE (note that R&D expenditure and costs are correlated, see equation 3), firms are able to seize a higher market share from rival firms in a distant KCE. Thus profits of insiders  $\Pi_{in}$  are higher in a distant than in a close KCE meaning that they prefer a distant collaboration.

	close RJV		distant RJV
$x_i$	$x_{in} > x_{out}$		$x_{in} > x_{out}$
$X_i$	$X_{in} > X_{ad} > X_{nonad}$		$X_{in} > X_{ad} > X_{enc}$
$\Pi_i$	$\Pi_{in} > \Pi_{ad} > \Pi_{nonad}$		$\Pi_{in} > \Pi_{ad} > \Pi_{enc}$
$x_{in}$	$x_{in}^{close}$	$<$	$x_{in}^{dist}$
$\Pi_{in}$	$\Pi_{in}^{close}$	$<$	$\Pi_{in}^{dist}$

Table 5: Equilibrium outcomes for a KCE

#### 4. Comparison of the different collaboration forms

In this section we compare the four alternative scenarios C, KC, KE and KCE from the viewpoints of firms, consumers, and a social planner. While respective profits are decisive for firms, consumers prefer a high consumer surplus, whereas a social planner intends to maximize overall welfare, i.e., the sum of producer and consumer surplus. We illustrate our results using exemplifying figures. Table 6 summarizes the results for the comparison of the different cooperation forms in profits, the consumer surplus and social welfare. General proofs and analytical derivations are in Appendix D.

	close RJV	distant RJV
$\Pi_{in}$	$\Pi^{KCE} > \Pi^{KE} > \Pi^{KC} > \Pi^C$	$\Pi^{KCE} > \Pi^{KE} > \Pi^{KC} > \Pi^C$
$\Pi_{av.out}$	$\Pi^C > \Pi^{KE} > \Pi^{KC} > \Pi^{KCE}$	$\Pi^{KC} > \Pi^C > \Pi^{KE} > \Pi^{KCE}$
$CS$	$CS^{KCE} > CS^{KC} > CS^C > CS^{KE}$	$CS^{KCE} > CS^C > CS^{KE} > CS^{KC}$
$W$	$W^{KCE} > W^{KC} > W^C > W^{KE}$	$W^{KCE} > W^C > W^{KE} > W^{KC}$

Table 6: Comparison of the different cooperation forms

#### 4.1. Profits

Due to the fact that in a RJV firms internalize knowledge spillovers and mitigate the free-rider problem (KC, KCE), and/or have access to complementary knowledge of a research partner (KE, KCE), insiders always profit from collaborative research irrespective of the technological distance to the partner ( $\Pi^k > \Pi^C$  for  $k = \{KC, KE, KCE\}$ ). Figure 6 illustrates that a higher collaboration intensity (in ascending order from left to right) leads to higher profits for the collaborating firms,  $\Pi^C < \Pi^{KC} < \Pi^{KE} < \Pi^{KCE}$ , with the highest insider profits resulting in a KCE and the lowest in a KC. Given this weakest form of collaboration insider firms only receive knowledge spillovers from their partner and their rivals. Although firms do not mutually exchange knowledge, a KC nonetheless leads to higher profits than research competition (C): (i) in a close KC by means of higher R&D investments, (ii) in a distant KC due to increasing market power and the resulting higher prices. A KE includes the mutual exchange of knowledge and therefore increases the R&D know-how available to the cooperating firms, expanding market demand and boosting insiders' profits. As a KCE combines both positive effects this collaboration form yields the highest profits. We summarize these results in



**Proposition 1.** *Insider firms always profit from research collaborations. The higher the intensity of the collaboration, the higher are the profits of insider firms.*

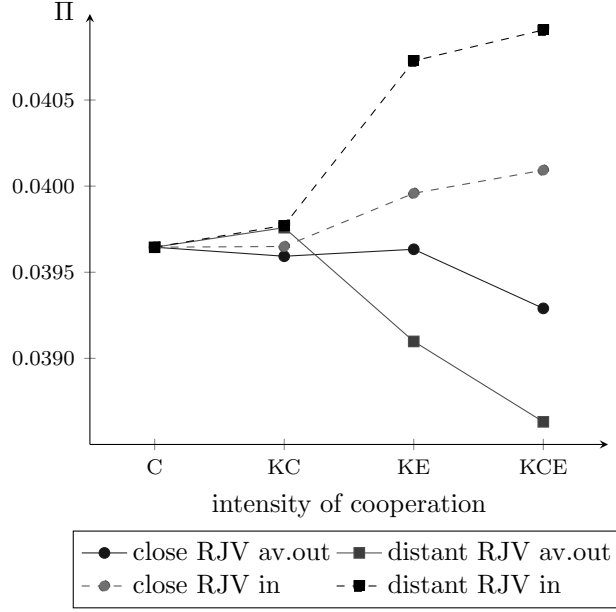


Figure 6: Average profits of insiders and outsiders ( $\gamma = 2.5; t = 1$ )

Figure 6 illustrates that for outsiders there is a negative trend between the research intensity of cooperating firms and profits earned. From the viewpoint of outsiders, a KCE is the worst outcome as profits are lowest. Outsider profits crucially depend on the distance to insider firms, where the worst location is being encompassed by insiders (see figures 1 and 2 for the definition of the different locations). Outsiders which are direct neighbors of a RJV have higher profits than outsiders located further away. For close RJs the reason is obvious: enabling spillovers from insiders to neighboring outsiders are higher than spillovers to non-adjacent outsiders. This in turn results in higher effective R&D investments. An encompassed outsider, however, suffers from the low prices set

by the two surrounding insiders as they reduce his market share and profits. We summarize these findings in

**Proposition 2.** *Profits of insiders (outsiders) are highest (lowest) in a KCE.*

#### 4.2. Consumers

Consumers care about their individual utility (see equation 4). They favor low product prices and a product deviation from their preference as small as possible in order to maximize utility. To compare the different scenarios we construct the consumer surplus (CS)

$$CS^k = 2 \sum_{i=1}^n \int_0^{D_i/2} (v - p_i - t\theta) d\theta \quad \text{for } k = \{C, KC, KE, KCE\}. \quad (14)$$

Integrating (recall that consumers are uniformly distributed along the circle with a mass normalized to unity,  $\sum_{i=1}^n D_i = 1$ ) yields

$$CS^k = v - \sum_{i=1}^n \left[ p_i D_i + \frac{t}{4} D_i^2 \right]. \quad (15)$$

As the reservation price ( $v$ ) is exogenously given and constant only the sum of the terms in brackets matters for a comparison. It consists of the product prices weighted with the respective share of consumers paying a price, and the utility loss consumers suffer from product deviation weighted with the quadratic share of consumers. Due to the fact that both components are utility diminishing we denote the relevant sum in brackets as consumers' utility loss (CUL). Figure 7 shows that the best outcome for consumers is a KCE as it yields the lowest level of CUL, meaning that consumer surplus is highest  $CS^{KCE} > CS^k$  for  $k = \{C, KC, KE\}$ : in a KCE consumers profit from high R&D investments of firms. In reducing marginal cost  $c$  intensive research activities lower the price-cost margin and therefore decrease equilibrium prices  $\hat{p}_i$  (see equation 8).

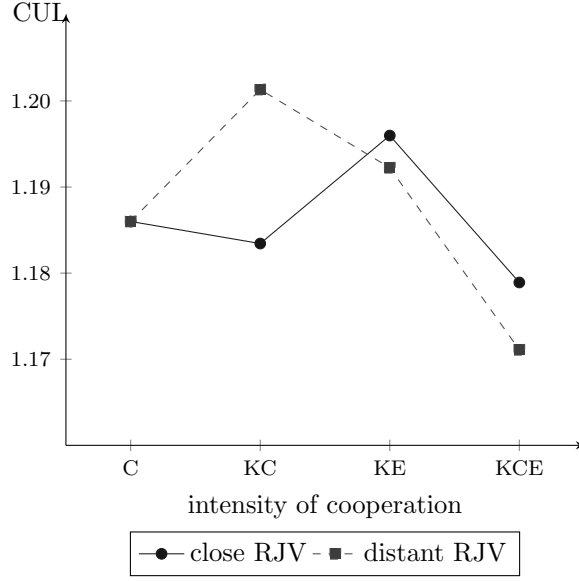


Figure 7: Consumers' utility loss ( $t = 1; c = 1; \gamma = 2.5$ )

Most interestingly, figure 7 reveals that research collaborations do not always benefit consumers. Comparing consumers' utility loss of RJVs with research competition (C), not all collaboration forms lead to a decreasing CUL: for a KE this is most obvious as the CUL is higher than with independent research for a close and a distant KE. Albeit firms in a KE exchange knowledge, insiders suffer from free riding and *reduce* their R&D expenditure compared to the situation with research competition (C): the higher the spillovers to outsider firms, the lower own R&D investments, as firms cannot internalize the spillovers effect. Consequently, effective R&D investments are relatively low and therefore cost reductions only minor, leading to higher prices than with independent research. The consumers' utility loss is highest in the case of a KC between two distant firms: outsider and insider firms set high prices because investments in cost reducing R&D are lowest as compared to the other scenarios. These findings

are summarized in

**Proposition 3.** *Research collaborations are not always beneficial for consumers.*

#### 4.3. Welfare

Social welfare balances these possibly countervailing effects. Total surplus (consumer surplus and producer surplus) on the unit circle is given by (Salop, 1979)

$$W = 2 \sum_{i=1}^n \int_0^{D_i/2} (v - c_i - t\theta) d\theta - \sum_{i=1}^n C(x_i). \quad (16)$$

Taking into account process innovations,  $c_i = c - X_i$ , and solving the integrals yields

$$W = v - c - \frac{t}{4} \sum_{i=1}^n D_i^2 + \sum_{i=1}^n D_i X_i - \frac{1}{2} \gamma \sum_{i=1}^n x_i^2. \quad (17)$$

As the reservation price ( $v$ ) and marginal costs ( $c$ ) are exogenously given and constant parameters, only the three last terms of equation (17) are decisive for social welfare in the alternative scenarios. Due to the fact that demand  $D_i$  and effective R&D investment  $X_i$  depend on the research effort  $x$  we denote these terms as the net Innovative Effect (nIE). The first term defines the utility loss each consumer suffers and therefore negatively affects social welfare. The second term is the overall effective R&D output weighted with the respective share of consumers while the last term reflects overall research cost. According to equation (17) welfare increases, the higher the net innovative effect is.

Figure 8 depicts a comparison of the net innovative effect across the different collaboration forms. As in a KCE spillovers are maximized and the free-rider problem is mitigated, nIE is highest meaning that social welfare is at its maximum,  $W^{KCE} > W^k$  for  $k = \{C, KC, KE\}$ . A social planner should therefore opt

for KCE collaborations what corresponds to the preferences of insider firms and consumers. Comparing figure 8 with figure 7 illustrates that a social planner's and consumers' preferences coincide. These results give us

**Proposition 4.** *Social welfare is highest in a KCE, which is also the preferred collaboration form of insider firms and consumers.*

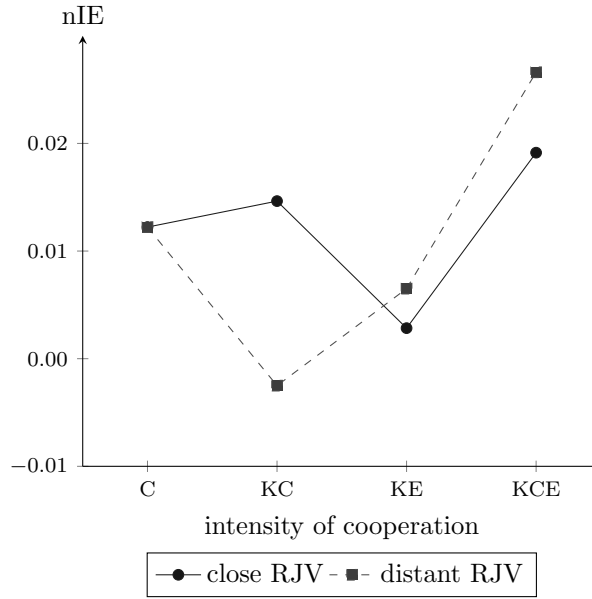


Figure 8: Net innovative effect ( $t = 1; \gamma = 2.5$ )

The central finding of this analysis is thus that not all forms of research cooperation are desirable for the economy, as some collaboration forms may decrease welfare as compared to the benchmark with independent research (C). The welfare implications fundamentally depend on the form of cooperation (KC, KE, KCE) and the technological proximity of research partners. Only a KCE increases social welfare in any case (close and distant RJV),  $W^{KCE} > W^C$ . On the contrary, close and distant KEs are welfare decreasing,  $W^{KE} < W^C$ , while in a KC the welfare effects depend on the technological distance of the

research partner: a close KC increases welfare,  $W^{KC} > W^C$ , while a distant KE decreases welfare,  $W^{KC} < W^C$ . These findings can be summarized in

**Proposition 5.** *Research collaborations do not necessarily have positive welfare implications for the economy as they may be welfare decreasing compared to research competition.*

## 5. Conclusion

The presented model extends the existing literature on the profitability of RJVs in two ways: by introducing technological proximity as knowledge transmission channel and by allowing for partial cooperation resulting in insider and outsider firms. Our central findings are: RJVs do not generally outperform competitive research, technological proximity and the intensity of cooperation play a decisive role for the welfare effects of a RJV, and cooperations where firms coordinate research activities and mutually exchange their knowledge (KCE) are welfare maximizing. This is due to the fact that with this collaboration form knowledge transfer increases to a maximum whereas the free rider problem is minimized. In addition our analysis revealed that firms prefer a technologically distant partner as this maximizes the exploitation of complementary knowledge in a research collaboration. At the same time a distant RJV is only welfare enhancing if collaboration is maximal, i.e., when firms coordinate research activities and exchange knowledge. All less intensive collaborations with a technologically distant research partner are welfare decreasing. Our results are in line with the empirical findings of Fisher et al. (2009) who find that accessing complementary knowledge and skills is one of the main objectives for firms to engage in R&D collaborations. Whether social and private interests coincide

depends on the intensity of research collaboration and the technological distance of a potential research partner. A cooperation of technologically distant firms jointly creating and exchanging knowledge (KCE) is most desirable for insider firms, consumers and a social planner as it yields highest profits, highest consumer surplus and highest innovative output. While this finding is in line with earlier contributions (e.g., Kamien et al., 1992), our results differ when taking into account our contribution regarding insider and outsider firms with varying technological proximity. With pure knowledge exchange (KE) private and social interests move in opposite directions as innovative output is lower and profits are higher irrespective of the choice of a research partner. In case of a pure Knowledge Creation Alliance (KC) there is a mixed outcome: for a close KC private and social interests coincide, whereas the cooperation with a technologically distant research partner results in the least desirable outcome regarding social welfare.

Our results can be related to several issues regarding the Framework Program of the European Commission: RJVs do not necessarily lead to a positive leverage effect on R&D activities. We find a considerable increase of R&D activity for RJVs where firms coordinate research activities and exchange knowledge (KCE), whereas for some collaboration forms R&D activity even decreases with a RJV. Furthermore, our results suggest that firms have intrinsic incentives to collaborate in R&D. This finding may explain the continuous decline of industry participation in the Seventh Framework Program reported in the Interim Evaluation (EC, 2010). The Interim Evaluation criticizes that the proliferation of funding instruments and programs has increased complexity and therefore proposes to sufficiently evaluate and revise existing funding schemes. In this con-

text the presented analysis contributes careful suggestions which of the different funding programs might be superior or less desirable. Moreover, the theoretical analysis points to scenarios where public funding might even provoke incentives for non-desirable, welfare-decreasing research collaboration.



## Appendix A. Knowledge Creation Alliance (KC)

### A.1. Knowledge Creation Alliance (KC): Close RJV

#### **Proof of $x_{in} > x_{out}$**

*Stage 1: R&D investments:* Two close competitors (e.g. firm 1 and 2) cooperate their R&D expenditure and therefore maximize joint profits  $\Pi_{joint}^{KC} = \Pi_1 + \Pi_2$  w.r.t.  $x_r$ , whereas outsiders maximize individual profits,  $\Pi_i$  for  $i \neq 1, 2$  w.r.t.  $x_i$ . From  $\partial \Pi_{joint}^{KC} / \partial x_r \stackrel{!}{=} 0$  and  $\partial \Pi_i / \partial x_i \stackrel{!}{=} 0$  we get the equilibrium R&D expenditure

$$x_r = x_{in} = \frac{2(377245\gamma^2 t^2 - 20900\gamma t + 176)}{19\gamma(857375\gamma^2 t^2 - 49590\gamma t + 424)} \quad (A.1)$$

$$x_3 = x_5 = x_{ad} = \frac{2(342950\gamma^2 t^2 - 20216\gamma t + 176)}{19\gamma(857375\gamma^2 t^2 - 49590\gamma t + 424)} \quad (A.2)$$

$$x_4 = x_{nonad} = \frac{2(342950\gamma^2 t^2 - 20748\gamma t + 176)}{19\gamma(857375\gamma^2 t^2 - 49590\gamma t + 424)} \quad (A.3)$$

For a nonnegative R&D expenditure (respecting the second order conditions<sup>11</sup>) the efficiency parameter requires  $\gamma > \frac{\sqrt{32729}+273}{9025t} \equiv \gamma_{KC}$ . This implies  $x_{in} > x_{ad} > x_{nonad}$ . Distinguishing between insider ( $x_{in}$ ) and outsider ( $x_{out}$ ) firms we get  $x_{in} > x_{out}$  in a close KC.

### A.2. Knowledge Creation Alliance (KC): Distant RJV

#### **Proof of $x_{in} < x_{out}$**

*Stage 1: R&D investments:* Two distant firms (e.g. firm 1 and 3) conduct a RJV and maximize joint profits  $\Pi_{joint}^{KC} = \Pi_1 + \Pi_3$ . Equilibrium R&D expenditure is

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<sup>11</sup>For the optimization w.r.t.  $x_r$  the second order condition (SOC) for a maximum requires  $\gamma > \frac{242}{9025t}$ ; for the optimization w.r.t.  $x_i$  the SOC for a maximum requires  $\gamma > \frac{200}{9025t}$ .

given by<sup>12</sup>

$$x_r = x_{in} = \frac{4(68590\gamma^2 t^2 - 3800\gamma t + 32)}{19\gamma(857375\gamma^2 t^2 - 42940\gamma t + 256)} \quad (\text{A.4})$$

$$x_2 = x_{enc} = \frac{4(171475\gamma^2 t^2 - 9044\gamma t + 32)}{19\gamma(857375\gamma^2 t^2 - 42940\gamma t + 256)} \quad (\text{A.5})$$

$$x_4 = x_5 = x_{ad} = \frac{4(171475\gamma^2 t^2 - 7448\gamma t + 32)}{19\gamma(857375\gamma^2 t^2 - 42940\gamma t + 256)}. \quad (\text{A.6})$$

In order to have a nonnegative R&D expenditure (respecting the SOC's) the efficiency parameter requires  $\gamma > \frac{2\sqrt{10361}+119}{9025t} \equiv \hat{\gamma}_{KC}$ .

If  $\hat{\gamma}_{KC} < \gamma < \frac{460}{9025t}$  we have  $x_{in} < x_{ad} < x_{enc}$  and for  $\gamma > \frac{460}{9025t}$  we get  $x_{in} < x_{enc} < x_{ad}$ . Thus, in a distant KC R&D expenditure of outsiders always exceeds that of insiders,  $x_{in} < x_{out}$ .

### A.3. Knowledge Creation Alliance (KC): Close RJV

#### **Proof of $\Pi_{in} > \Pi_{out}$**

In order to compute equilibrium profits we first have to calculate effective R&D investment levels. Substituting the equilibrium R&D expenditure into equation (2), we have the effective R&D investments

$$X_r = X_{in} = \frac{2(359195\gamma^2 t^2 - 20624\gamma t + 176)}{\gamma(4286875\gamma^2 t^2 - 247950\gamma t + 2120)} \quad (\text{A.7})$$

$$X_3 = X_5 = X_{ad} = \frac{2(355585\gamma^2 t^2 - 20580\gamma t + 176)}{\gamma(4286875\gamma^2 t^2 - 247950\gamma t + 2120)} \quad (\text{A.8})$$

$$X_4 = X_{nonad} = \frac{2(353780\gamma^2 t^2 - 20572\gamma t + 176)}{\gamma(4286875\gamma^2 t^2 - 247950\gamma t + 2120)} \quad (\text{A.9})$$

#### **Proof of $X_{in} > X_{ad} > X_{nonad}$**

For  $X_{in} > X_{ad}$  the difference between equation (A.7) and (A.8) has to be positive,  $X_{in} - X_{ad} = 3610\gamma t - 44 > 0$  what holds for  $\gamma > \frac{110}{9025t}$ .

For  $X_{ad} > X_{nonad}$  the difference  $X_{ad} - X_{nonad} = 1805\gamma t - 8 > 0$  what holds for

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<sup>12</sup>The SOC for  $x_r$  requires  $\gamma > \frac{32}{9025t}$  and for  $x_2$  and  $x_4$   $\gamma > \frac{200}{9025t}$ .

$$\gamma > \frac{40}{9025t}.$$

Thus, for  $\gamma \geq \gamma_{KC}$  we have  $X_{in} > X_{ad} > X_{nonad}$ . Since effective R&D investments and demand are correlated (for details see Section 2) this implies  $D_{in} > D_{ad} > D_{nonad}$ .

Inserting equilibrium R&D expenditure and effective R&D investments into equation (9) and (10) equilibrium profits amount to

$$\Pi_{in} = \left( \frac{1}{5} + \frac{39710\gamma^2 t^2 - 456\gamma t}{95\gamma t(857375\gamma^2 t^2 - 49590\gamma t + 424)} \right)^2 t - \frac{6050(34295\gamma^2 t^2 - 1900\gamma t + 16)^2}{9025\gamma(857375\gamma^2 t^2 - 49590\gamma t + 424)^2} \quad (\text{A.10})$$

$$\Pi_{ad} = \left( \frac{1}{5} + \frac{304\gamma t - 18050\gamma^2 t^2}{95\gamma t(857375\gamma^2 t^2 - 49590\gamma t + 424)} \right)^2 t - \frac{200(171475\gamma^2 t^2 - 10108\gamma t + 88)^2}{9025\gamma(857375\gamma^2 t^2 - 49590\gamma t + 424)^2} \quad (\text{A.11})$$

$$\Pi_{nonad} = \left( \frac{1}{5} + \frac{304\gamma t - 43320\gamma^2 t^2}{95\gamma t(857375\gamma^2 t^2 - 49590\gamma t + 424)} \right)^2 t - \frac{200(171475\gamma^2 t^2 - 10374\gamma t + 88)^2}{9025\gamma(857375\gamma^2 t^2 - 49590\gamma t + 424)^2} \quad (\text{A.12})$$

and are positive for  $\gamma \geq \gamma_{KC}$ .

**Proof of  $\Pi_{in} > \Pi_{ad} > \Pi_{nonad}$**

For  $\Pi_{in} > \Pi_{ad}$ , the following inequality has to hold

$$t(D_{in}^2 - D_{ad}^2) + \frac{1}{2}\gamma(x_{ad}^2 - x_{in}^2) > 0. \quad (\text{A.13})$$

Inserting the equilibrium values and rearranging yields

$$340463613\gamma^3 t^3 - 19589304\gamma^2 t^2 + 172520\gamma t + 48 > 0$$

which is positive for  $\gamma t > 0$ .

To assure  $\Pi_{ad} > \Pi_{nonad}$  the following inequality has to hold

$$t(D_{ad}^2 - D_{nonad}^2) + \frac{1}{2}\gamma(x_{nonad}^2 - x_{ad}^2) > 0 \quad (\text{A.14})$$

$$433317325\gamma^3 t^3 - 35481607\gamma^2 t^2 + 795872\gamma t - 4928 > 0. \quad (\text{A.15})$$

What is fulfilled whenever  $\frac{-\sqrt{123321}+539}{18050t} < \gamma < \frac{400}{18050t}$  and  $\gamma > \frac{\sqrt{123321}+539}{18050t}$ .

Ensuring a nonnegative R&D expenditure and the SOC, the efficiency parameter requires  $\gamma \geq \gamma_{KC}$ , what gives us  $\Pi_{in} > \Pi_{ad} > \Pi_{nonad}$ . Thus, in a close KC profits of insiders always exceed that of outsiders,  $\Pi_{in} > \Pi_{out}$ .

#### A.4. Knowledge Creation Alliance (KC): Distant RJV

**Proof of  $\Pi_{ad} > \Pi_{in} > \Pi_{enc}$**

For equilibrium profits we first calculate effective R&D investments

$$X_r = X_{in} = \frac{9739780\gamma^2 t^2 - 474848\gamma t + 2432}{95\gamma(857375\gamma^2 t^2 - 42940\gamma t + 256)} \quad (\text{A.16})$$

$$X_2 = X_{enc} = \frac{9739780\gamma^2 t^2 - 481232\gamma t + 2432}{95\gamma(857375\gamma^2 t^2 - 42940\gamma t + 256)} \quad (\text{A.17})$$

$$X_4 = X_5 = X_{ad} = \frac{10151320\gamma^2 t^2 - 483056\gamma t + 2432}{95\gamma(857375\gamma^2 t^2 - 42940\gamma t + 256)}. \quad (\text{A.18})$$

**Proof of  $X_{ad} > X_{in} > X_{enc}$**

The calculation is equivalent to a close KC and therefore omitted. If  $\gamma \geq \hat{\gamma}_{KC}$  we have  $X_{ad} > X_{in} > X_{enc}$ .

Inserting equilibrium R&D expenditure and effective R&D investments into

equation (9) and (10) equilibrium profits amount to

$$\Pi_{in} = \left( \frac{1}{5} + \frac{-86640\gamma^2 t^2 + 2736\gamma t}{95\gamma t(857375\gamma^2 t^2 - 42940\gamma t + 256)} \right)^2 t - \frac{800(34295\gamma^2 t^2 - 1900\gamma t + 16)^2}{9025\gamma(857375\gamma^2 t^2 - 42940\gamma t + 256)^2} \quad (\text{A.19})$$

$$\Pi_{enc} = \left( \frac{1}{5} + \frac{-43320\gamma^2 t^2 - 1824\gamma t}{95\gamma t(857375\gamma^2 t^2 - 42940\gamma t + 256)} \right)^2 t - \frac{200(171475\gamma^2 t^2 - 9044\gamma t + 32)^2}{9025\gamma(857375\gamma^2 t^2 - 42940\gamma t + 256)^2} \quad (\text{A.20})$$

$$\Pi_{ad} = \left( \frac{1}{5} + \frac{108300\gamma^2 t^2 - 1824\gamma t}{95\gamma t(857375\gamma^2 t^2 - 42940\gamma t + 256)} \right)^2 t - \frac{200(171475\gamma^2 t^2 - 7448\gamma t + 32)^2}{9025\gamma(857375\gamma^2 t^2 - 42940\gamma t + 256)^2}. \quad (\text{A.21})$$

**Proof of  $\Pi_{ad} > \Pi_{in} > \Pi_{enc}$**

Ensuring nonnegative R&D expenditure and the SOC's, the efficiency parameter requires  $\gamma \geq \hat{\gamma}_{KC}$ , implying  $\Pi_{ad} > \Pi_{in} > \Pi_{enc}$ . Thus, in a distant KC profits of the adjacent outsiders always exceed that of insiders.

**Proof of  $x_{in}^{close} > x_{in}^{dist}$**

R&D expenditure of insiders in a KC is given by equation (A.1) and (A.4).

In order to have  $x_{in}^{close} > x_{in}^{dist}$  the following inequation has to hold

$$6001625\gamma^2 t^2 - 273980\gamma t + 1120 > 0$$

Applying the quadratic formula yields

$$\gamma_1 = \frac{2\sqrt{10361} + 119}{9025t}, \gamma_2 = \frac{\sqrt{32729} + 273}{9025t}$$

The solution of the quadratic formula is smaller than the efficiency parameter defined above,  $\gamma_{1/2} < \gamma_{KC}$  and  $\gamma_{1/2} < \hat{\gamma}_{KC}$ , implying  $x_{in}^{close} > x_{in}^{dist}$  in a KC.  $\square$

**Proof of  $\Pi_{KC}^{dist} > \Pi_{KC}^{close}$**

Profits are given by equation (A.10) and (A.19). For  $\gamma > \gamma_{KC}$  we get  $\Pi_{KC}^{dist} >$

$\Pi_{KC}^{close}$ .

## Appendix B. Knowledge Exchange Alliance (KE)

### B.1. Knowledge Exchange Alliance (KE): Close RJV

*Stage 1: R&D investments* Firms maximize individual profits  $\Pi_i$  w.r.t. R&D expenditure  $x_i$ . Two close firms (e.g. firm 1 and 2) exchange knowledge ( $\beta_{1,2}^{KE} = 1$ ). From the maximization of  $\partial \Pi_i / \partial x_i \stackrel{!}{=} 0$  we get:<sup>13</sup>

$$x_1 = x_2 = x_{in} = \frac{12/25(9025\gamma t - 320)}{19\gamma(9025\gamma t - 344)} \quad (\text{B.1})$$

$$x_3 = x_5 = x_{ad} = \frac{18/25(9025\gamma t - 348)}{19\gamma(9025\gamma t - 344)} \quad (\text{B.2})$$

$$x_4 = x_{nonad} = \frac{20/25(9025\gamma t - 384)}{19\gamma(9025\gamma t - 344)}. \quad (\text{B.3})$$

For positive R&D expenditure (respecting the SOC's), the efficiency parameter has to exceed  $\gamma > \frac{384}{9025t} \equiv \gamma_{KE}$ . Define  $\bar{\gamma}_{close} \equiv \frac{404}{9025t}$  and  $\bar{\bar{\gamma}}_{close} \equiv \frac{480}{9025t}$ . A comparison of R&D expenditure then yields

for  $\gamma_{KE} \leq \gamma < \bar{\gamma}_{close}$  we have  $x_{in} > x_{ad} > x_{nonad}$ ,

for  $\bar{\gamma}_{close} \leq \gamma < \bar{\bar{\gamma}}_{close}$  we have  $x_{ad} > x_{in} > x_{nonad}$ ,

for  $\bar{\bar{\gamma}}_{close} \leq \gamma < \frac{708}{9025t}$  we have  $x_{ad} > x_{nonad} > x_{in}$  and

for  $\gamma > \frac{708}{9025t}$  we have  $x_{nonad} > x_{ad} > x_{in}$ .

Distinguishing between insider ( $x_{in}$ ) and outsider ( $x_{out}$ ) firms we get  $x_{in} > x_{out}$

for  $\gamma < \bar{\gamma}_{close} \equiv \frac{404}{9025t}$  and  $x_{in} < x_{out}$  for  $\gamma > \bar{\bar{\gamma}}_{close} \equiv \frac{480}{9025t}$ .

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<sup>13</sup>The SOC's for  $x_1, x_2$  require  $\gamma > \frac{72}{9025t}$ , for  $x_3, x_5$   $\gamma > \frac{162}{9025t}$  and for  $x_4$   $\gamma > \frac{200}{9025t}$ .

### B.2. Knowledge Exchange Alliance (KE): Distant RJV

*Stage 1: R&D investments* Firms maximize individual profits  $\Pi_i$  w.r.t. R&D expenditure  $x_i$ . Two distant firms (e.g. firm 1 and 3) exchange knowledge ( $\beta_{1,3}^{KE} = 1$ ). From the maximization of  $\partial \Pi_i / \partial x_i \stackrel{!}{=} 0$  we get<sup>14</sup>

$$x_1 = x_3 = x_{in} = \frac{14(171475\gamma^2 t^2 - 5130\gamma t - 72)}{19\gamma(4286875\gamma^2 t^2 - 247950\gamma t + 3032)} \quad (\text{B.4})$$

$$x_4 = x_5 = x_{ad} = \frac{18(171475\gamma^2 t^2 - 11932\gamma t + 224)}{19\gamma(4286875\gamma^2 t^2 - 247950\gamma t + 3032)} \quad (\text{B.5})$$

$$x_2 = x_{enc} = \frac{20(171475\gamma^2 t^2 - 15466\gamma t + 1512/5)}{19\gamma(4286875\gamma^2 t^2 - 247950\gamma t + 3032)}. \quad (\text{B.6})$$

In order to have a nonnegative R&D expenditure (respecting the SOC's) the efficiency parameter requires  $\gamma > \frac{\sqrt{22009}+407}{9025t} \equiv \hat{\gamma}_{KE}$ . Define  $\bar{\gamma}_{\text{dist}} \equiv \frac{3\sqrt{127129}+1881}{18050t}$  and  $\bar{\bar{\gamma}}_{\text{dist}} \equiv \frac{\sqrt{189529}+625}{5415t}$ . A comparison of R&D expenditure then yields

For  $\hat{\gamma}_{KE} \leq \gamma < \bar{\gamma}_{\text{dist}}$  we have  $x_{in} > x_{ad} > x_{enc}$ ,

for  $\bar{\gamma}_{\text{dist}} \leq \gamma < \bar{\bar{\gamma}}_{\text{dist}}$  we have  $x_{ad} > x_{in} > x_{enc}$ ,

for  $\bar{\bar{\gamma}}_{\text{dist}} \leq \gamma < \frac{8\sqrt{16699}+1244}{9025t}$  we have  $x_{ad} > x_{enc} > x_{in}$ ,

and for  $\gamma > \frac{8\sqrt{16699}+1244}{9025t}$  we have  $x_{enc} > x_{ad} > x_{in}$ .

Thus, in a distant (KE) R&D expenditure of insider are smaller (higher) than that of outsiders if  $\gamma > \bar{\gamma}_{\text{dist}}$  ( $\gamma < \bar{\gamma}_{\text{dist}}$ ).

### B.3. Knowledge Exchange Alliance (KE): Close RJV

#### **Proof of $\Pi_{in} > \Pi_{out}$**

In order to compute equilibrium profits we first have to calculate effective R&D

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<sup>14</sup>The SOC's for  $x_1, x_3$  require  $\gamma > \frac{98}{9025t}$ , for  $x_4, x_5$   $\gamma > \frac{162}{9025t}$  and for  $x_2$   $\gamma > \frac{200}{9025t}$ .

investment levels. The effective R&D investments result in

$$X_1 = X_2 = X_{in} = \frac{4/125(731025\gamma t - 27348)}{19\gamma(9025\gamma t - 344)} \quad (\text{B.7})$$

$$X_3 = X_5 = X_{ad} = \frac{4/125(722000\gamma t - 27168)}{19\gamma(9025\gamma t - 344)} \quad (\text{B.8})$$

$$X_4 = X_{nonad} = \frac{4/125(712975\gamma t - 26988)}{19\gamma(9025\gamma t - 344)}. \quad (\text{B.9})$$

**Proof of  $X_{in} > X_{ad} > X_{nonad}$**

For  $\gamma \geq \gamma_{KE}$  we have  $X_{in} > X_{ad} > X_{nonad}$  and therefore

$$D_{in} > D_{ad} > D_{nonad}.$$

The equilibrium profits amount to

$$\Pi_{in} = \left( \frac{1}{5} + \frac{2280\gamma t}{475\gamma t(9025\gamma t - 344)} \right)^2 t - \frac{72(9025\gamma t - 320)^2}{475^2\gamma(9025\gamma t - 344)^2} \quad (\text{B.10})$$

$$\Pi_{ad} = \left( \frac{1}{5} + \frac{-380\gamma t}{475\gamma t(9025\gamma t - 344)} \right)^2 t - \frac{162(9025\gamma t - 348)^2}{475^2\gamma(9025\gamma t - 344)^2} \quad (\text{B.11})$$

$$\Pi_{nonad} = \left( \frac{1}{5} + \frac{-3800\gamma t}{475\gamma t(9025\gamma t - 344)} \right)^2 t - \frac{200(9025\gamma t - 384)^2}{475^2\gamma(9025\gamma t - 344)^2}. \quad (\text{B.12})$$

**Proof of  $\Pi_{in} > \Pi_{ad} > \Pi_{nonad}$**

Obviously, whenever  $\gamma \geq \gamma_{KE}$  we have  $\Pi_{in} > \Pi_{ad} > \Pi_{nonad}$ . Thus, in a close

KE profits of insiders always exceed that of outsiders,  $\Pi_{in} > \Pi_{out}$ .

#### B.4. Knowledge Exchange Alliance (KE): Distant RJV

**Proof of  $\Pi_{in} > \Pi_{out}$**

In order to compute equilibrium profits we first have to calculate effective R&D

investment levels. Effective R&D investments amount to

$$X_1 = X_3 = X_{in} = \frac{62416900\gamma^2 t^2 - 3673688\gamma t + 46368}{95\gamma(4286875\gamma^2 t^2 - 247950\gamma t + 3032)} \quad (\text{B.13})$$

$$X_4 = X_5 = X_{ad} = \frac{57272650\gamma^2 t^2 - 3435504\gamma t + 46368}{95\gamma(4286875\gamma^2 t^2 - 247950\gamma t + 3032)} \quad (\text{B.14})$$

$$X_2 = X_{enc} = \frac{54872000\gamma^2 t^2 - 3409816\gamma t + 46368}{95\gamma(4286875\gamma^2 t^2 - 247950\gamma t + 3032)}. \quad (\text{B.15})$$



**Proof of  $X_{in} > X_{ad} > X_{enc}$**

If  $\gamma \geq \hat{\gamma}_{KE}$  we have  $X_{in} > X_{ad} > X_{enc}$  and thus  $D_{in} > D_{ad} > D_{enc}$ .

Equilibrium profits are given by

$$\Pi_{in} = \left( \frac{1}{5} + \frac{2274300\gamma^2 t^2 - 91808\gamma t}{95\gamma t(4286875\gamma^2 t^2 - 247950\gamma t + 3032)} \right)^2 t - \frac{2450(-171475\gamma^2 t^2 + 5130\gamma t + 72)^2}{9025\gamma(4286875\gamma^2 t^2 - 247950\gamma t + 3032)^2} \quad (\text{B.16})$$

$$\Pi_{enc} = \left( \frac{1}{5} + \frac{-2635300\gamma^2 t^2 + 86032\gamma t}{95\gamma t(4286875\gamma^2 t^2 - 247950\gamma t + 3032)} \right)^2 t - \frac{200(857375\gamma^2 t^2 - 77330\gamma t + 152)^2}{9025\gamma(4286875\gamma^2 t^2 - 247950\gamma t + 3032)^2} \quad (\text{B.17})$$

$$\Pi_{ad} = \left( \frac{1}{5} + \frac{-956650\gamma^2 t^2 + 48792\gamma t}{95\gamma t(4286875\gamma^2 t^2 - 247950\gamma t + 3032)} \right)^2 t - \frac{4050(171475\gamma^2 t^2 - 11932\gamma t + 224)^2}{9025\gamma(4286875\gamma^2 t^2 - 247950\gamma t + 3032)^2}. \quad (\text{B.18})$$

**Proof of  $\Pi_{in} > \Pi_{ad} > \Pi_{enc}$**

For  $\gamma > \hat{\gamma}_{KE}$  we have  $\Pi_{in} > \Pi_{ad} > \Pi_{enc}$ . Thus, in a distant (KE) profits of insiders always exceed that of outsiders,  $\Pi_{in} > \Pi_{out}$ .

**Proof of  $x_{in}^{dist} > x_{in}^{close}$**

R&D expenditure is given by equation (B.1) and (B.4). For  $\gamma > \hat{\gamma}_{KE}$  we get

$$x_{in}^{dist} > x_{in}^{close}.$$

**Proof of  $\Pi_{KE}^{dist} > \Pi_{KE}^{close}$**

Profits are given by equation (B.10) and (B.16). For  $\gamma > \hat{\gamma}_{KE}$  we get  $\Pi_{KE}^{dist} >$

$$\Pi_{KE}^{close}.$$

## Appendix C. Knowledge Creation and Exchange Alliance (KCE)

### C.1. Knowledge Creation Exchange Alliance (KCE): Close RJV

#### **Proof of $x_{in} > x_{out}$**

*Stage 1: R&D investments* Two close firms (e.g. firm 1 and 2) exchange knowledge ( $\beta_{1,2}^{KCE} = 1$ ). In the first stage firm 1 and 2 cooperate their R&D activities. Therefore, they maximize joint profits  $\Pi_{RJV} = \Pi_1 + \Pi_2$ , whereas all other competitors maximize their individual profits.<sup>15</sup> Simultaneously solving the first order conditions yields

$$x_r = x_{in} = \frac{24/25(9025\gamma t - 320)}{19\gamma(9025\gamma t - 488)} \quad (C.1)$$

$$x_3 = x_5 = x_{ad} = \frac{18/25(9025\gamma t - 516)}{19\gamma(9025\gamma t - 488)} \quad (C.2)$$

$$x_4 = x_{nonad} = \frac{20/25(9025\gamma t - 768)}{19\gamma(9025\gamma t - 488)}. \quad (C.3)$$

For positive R&D expenditure (respecting the SOC)  $\gamma > \frac{768}{9025t} \equiv \gamma_{KCE}$  needs to hold.

For  $\gamma > \frac{3036}{9025t}$  we have  $x_{nonad} > x_{ad}$  and for  $\gamma > \frac{-384}{9025t}$  we have  $x_{in} > x_{nonad} > x_{ad}$ . Therefore we have  $x_{in} > x_{ad} > x_{nonad}$  for  $\gamma_{KCE} < \gamma < \frac{3036}{9025t}$  and  $x_{in} > x_{nonad} > x_{ad}$  for  $\gamma > \frac{3036}{9025t}$ . Thus, in a close KCE R&D expenditure of insiders always exceeds that of outsiders,  $x_{in} > x_{out}$ .

### C.2. Knowledge Creation and Exchange Alliance (KCE): Distant RJV

#### **Proof of $x_{in} > x_{out}$**

*Stage 1: R&D investments* Two distant firms (e.g. firm 1 and 3) exchange knowledge ( $\beta_{1,3}^{KCE} = 1$ ). In the first stage firm 1 and 3 cooperate their R&D

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<sup>15</sup>The SOC for  $x_{in}$  requires  $\gamma > \frac{288}{9025t}$ ,  $x_{ad}$  requires  $\gamma > \frac{162}{9025t}$  and  $x_{nonad}$  requires  $\gamma > \frac{200}{9025t}$ .

activities. Therefore, they maximize joint profits  $\Pi_{RJV} = \Pi_1 + \Pi_3$ , whereas all other competitors maximize their individual profits.<sup>16</sup> R&D expenditure is given by

$$x_1 = x_3 = x_{in} = \frac{28(171475\gamma^2 t^2 - 5130\gamma t - 72)}{19\gamma(4286875\gamma^2 t^2 - 341050\gamma t + 6784)} \quad (C.4)$$

$$x_4 = x_5 = x_{ad} = \frac{(171475\gamma^2 t^2 - 17784\gamma t + 448)}{19\gamma(4286875\gamma^2 t^2 - 341050\gamma t + 6784)} \quad (C.5)$$

$$x_2 = x_{enc} = \frac{20(171475\gamma^2 t^2 - 22382\gamma t + 3024/5)}{19\gamma(4286875\gamma^2 t^2 - 341050\gamma t + 6784)}. \quad (C.6)$$

In order to have a nonnegative R&D expenditure (respecting the SOC's) the efficiency parameter requires  $\gamma > \frac{\sqrt{59641+589}}{9025t} \equiv \hat{\gamma}_{KCE}$ .

If  $\hat{\gamma}_{KCE} < \gamma < \frac{2\sqrt{464521+839}}{9025t}$  we have  $x_{in} > x_{ad} > x_{enc}$  and for  $\gamma > \frac{2\sqrt{464521+839}}{9025t}$  we have  $x_{in} > x_{enc} > x_{ad}$ . Thus, in a distant KCE R&D expenditure of insiders always exceeds that of outsiders,  $x_{in} > x_{out}$ .

### C.3. Knowledge Creation and Exchange Alliance (KCE): Close RJV

#### **Proof of $\Pi_{in} > \Pi_{out}$**

The effective R&D investments are given by

$$X_r = X_{in} = \frac{4/125(1001775\gamma t - 49296)}{19\gamma(9025\gamma t - 488)} \quad (C.7)$$

$$X_3 = X_5 = X_{ad} = \frac{4/125(938600\gamma t - 49296)}{19\gamma(9025\gamma t - 488)} \quad (C.8)$$

$$X_4 = X_{nonad} = \frac{4/125(875425\gamma t - 49296)}{19\gamma(9025\gamma t - 488)}. \quad (C.9)$$

#### **Proof of $X_{in} > X_{ad} > X_{nonad}$**

For  $\gamma \geq \gamma_{KCE}$  the effective R&D investments are positive and  $X_{in} > X_{ad} > X_{nonad}$  (implying  $D_{in} > D_{ad} > D_{nonad}$ ).

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<sup>16</sup>The SOC for  $x_{in}$  requires  $\gamma > \frac{392}{9025t}$ ,  $x_{ad}$  requires  $\gamma > \frac{162}{9025t}$  and  $x_{enc}$  requires  $\gamma > \frac{200}{9025t}$ .

Equilibrium profits amount to

$$\Pi_{in} = \left( \frac{1}{5} + \frac{15960\gamma t}{475\gamma t(9025\gamma t - 488)} \right)^2 t - \frac{288(9025\gamma t - 320)^2}{475^2\gamma(9025\gamma t - 488)^2} \quad (C.10)$$

$$\Pi_{ad} = \left( \frac{1}{5} + \frac{-2660\gamma t}{475\gamma t(9025\gamma t - 488)} \right)^2 t - \frac{162(9025\gamma t - 516)^2}{475^2\gamma(9025\gamma t - 488)^2} \quad (C.11)$$

$$\Pi_{nonad} = \left( \frac{1}{5} + \frac{-26600\gamma t}{475\gamma t(9025\gamma t - 488)} \right)^2 t - \frac{200(9025\gamma t - 768)^2}{475^2\gamma(9025\gamma t - 488)^2}. \quad (C.12)$$

**Proof of  $\Pi_{in} > \Pi_{ad} > \Pi_{nonad}$**

For  $\gamma \geq \gamma_{KCE}$  profits are positive and  $\Pi_{in} > \Pi_{ad} > \Pi_{nonad}$ . Thus, in a close KCE profits of insiders always exceed that of outsiders,  $\Pi_{in} > \Pi_{out}$ .

#### C.4. Knowledge Creation Exchange Alliance (KCE): Distant RJV

**Proof of  $\Pi_{in} > \Pi_{out}$**

In order to compute equilibrium profits we first have to calculate effective R&D investment levels. Effective R&D investments are given by

$$X_r = X_{in} = \frac{86423400\gamma^2 t^2 - 5787856\gamma t + 92736}{95\gamma(4286875\gamma^2 t^2 - 341050\gamma t + 6784)} \quad (C.13)$$

$$X_2 = X_{enc} = \frac{74077200\gamma^2 t^2 - 5307992\gamma t + 92736}{95\gamma(4286875\gamma^2 t^2 - 341050\gamma t + 6784)} \quad (C.14)$$

$$X_4 = X_5 = X_{ad} = \frac{76477850\gamma^2 t^2 - 5373048\gamma t + 92736}{95\gamma(4286875\gamma^2 t^2 - 341050\gamma t + 6784)}. \quad (C.15)$$

**Proof of  $X_{in} > X_{ad} > X_{enc}$**

If  $\gamma > \hat{\gamma}_{KCE}$ , we have  $X_{in} > X_{ad} > X_{enc}$ .

Equilibrium profits are given by

$$\Pi_{in} = \left( \frac{1}{5} + \frac{4043200\gamma^2 t^2 - 163096\gamma t}{95\gamma t(4286875\gamma^2 t^2 - 341050\gamma t + 6784)} \right)^2 t - \frac{9800(-171475\gamma^2 t^2 + 5130\gamma t + 72)^2}{9025\gamma(4286875\gamma^2 t^2 - 341050\gamma t + 6784)^2} \quad (C.16)$$

$$\Pi_{enc} = \left( \frac{1}{5} + \frac{-4151500\gamma^2 t^2 + 158384\gamma t}{95\gamma t(4286875\gamma^2 t^2 - 341050\gamma t + 6784)} \right)^2 t - \frac{5000(171475\gamma^2 t^2 - 22382\gamma t + 3024/5)^2}{9025\gamma(4286875\gamma^2 t^2 - 341050\gamma t + 6784)^2} \quad (C.17)$$

$$\Pi_{ad} = \left( \frac{1}{5} + \frac{-1967450\gamma^2 t^2 + 83904\gamma t}{95\gamma t(4286875\gamma^2 t^2 - 341050\gamma t + 6784)} \right)^2 t - \frac{4050(171475\gamma^2 t^2 - 17784\gamma t + 448)^2}{9025\gamma(4286875\gamma^2 t^2 - 341050\gamma t + 6784)^2}. \quad (C.18)$$

**Proof of  $\Pi_{in} > \Pi_{ad} > \Pi_{enc}$**

If  $\gamma > \hat{\gamma}_{KCE}$  we have  $\Pi_{in} > \Pi_{ad} > \Pi_{enc}$ . Thus, in a distant KCE profits of insiders always exceed that of outsiders,  $\Pi_{in} > \Pi_{out}$ .

**Proof of  $x_{in}^{dist} > x_{in}^{close}$**

R&D expenditure is given by equation (C.1) and (C.4). For  $\gamma > \hat{\gamma}_{KCE}$  we get

$$x_{in}^{dist} > x_{in}^{close}.$$

**Proof of  $\Pi_{KCE}^{dist} > \Pi_{KCE}^{close}$**

Profits are given by equation (C.10) and (C.16). For  $\gamma > \hat{\gamma}_{KCE}$  we get  $\Pi_{KCE}^{dist} >$

$$\Pi_{KCE}^{close}.$$

## Appendix D. Comparison of different collaboration forms

### D.1. Proof of Proposition 1

#### Close RJV

**Proof of  $\Pi^k > \Pi^C$  for  $k = \{KC, KE, KCE\}$  and  $\Pi_{in}^{KCE} > \Pi_{in}^{KE} > \Pi_{in}^{KC} > \Pi^C$**

Profits of insiders are given by

$$\Pi^C = \left(\frac{1}{5}\right)^2 t - \frac{8}{9025\gamma} \quad (\text{D.1})$$

$$\Pi_{in}^{KC} = \left(\frac{1}{5} + \frac{754490\gamma^2 t^2 - 8664\gamma t}{9025\gamma t(171475\gamma^2 t^2 - 9918\gamma t + 424/5)}\right)^2 t - \frac{242(34295\gamma^2 t^2 - 1900\gamma t + 16)^2}{9025\gamma(171475\gamma^2 t^2 - 9918\gamma t + 424/5)^2} \quad (\text{D.2})$$

$$\Pi_{in}^{KE} = \left(\frac{1}{5} + \frac{43320\gamma t}{9025\gamma t(9025\gamma t - 344)}\right)^2 t - \frac{72(1805\gamma t - 64)^2}{9025\gamma(9025\gamma t - 344)^2} \quad (\text{D.3})$$

$$\Pi_{in}^{KCE} = \left(\frac{1}{5} + \frac{303240\gamma t}{9025\gamma t(9025\gamma t - 488)}\right)^2 t - \frac{288(1805\gamma t - 64)^2}{9025\gamma(9025\gamma t - 488)^2}. \quad (\text{D.4})$$

In order to make the different cooperation alliances comparable, we have to presume the most restrictive value for  $\gamma$  where the SOC's and non negativity conditions on equilibrium R&D expenditure are fulfilled, which is  $\gamma_{KCE}$ , implying  $\Pi_{in}^{KCE} > \Pi_{in}^{KE} > \Pi_{in}^{KC} > \Pi^C$ . Thus, profits of insiders are always higher in a close RJV than with R&D competition,  $\Pi^k > \Pi^C$  for  $k = \{KC, KE, KCE\}$ .

#### Distant RJV

**Proof of**  $\Pi^k > \Pi^C$  for  $k = \{KC, KE, KCE\}$  and  $\Pi_{in}^{KCE} > \Pi_{in}^{KE} > \Pi_{in}^{KC} > \Pi^C$

Profits of insiders for C, KC, KE and KCE are presented in equation (D.1), (A.19), (B.16) and (C.16). For  $\gamma \geq \hat{\gamma}_{KCE}$  we have  $\Pi^C < \Pi_{in}^{KC} < \Pi_{in}^{KE} < \Pi_{in}^{KCE}$ . Thus, profits of insiders are always higher in a distant RJV than with R&D competition C,  $\Pi^k > \Pi^C$  for  $k = \{KC, KE, KCE\}$ .

#### D.2. Proof of Proposition 2

##### Close RJV

**Proof of**  $\Pi_{in}^{KCE} > \Pi_{in}^k$  for  $k = \{C, KC, KE\}$

see Proof of Proposition 1

**Proof of**  $\Pi_{av.out}^{KCE} < \Pi_{av.out}^k$  for  $k = \{C, KC, KE\}$

and  $\Pi^C > \Pi_{av.out}^{KE} > \Pi_{av.out}^{KC} > \Pi_{av.out}^{KCE}$

The average profits of outsiders are given by  $\Pi_{av.out}^k \equiv \frac{1}{3} \sum 2\Pi_{ad}^k + \Pi_{nonad}^k$  for  $k = \{C, KC, KE, KCE\}$ .

Iff  $\gamma \geq \gamma_{KCE}$  we have  $\Pi^C > \Pi_{av.out}^{KE} > \Pi_{av.out}^{KC} > \Pi_{av.out}^{KCE}$ . Thus, profits of outsiders are smallest in a close KCE,  $\Pi_{av.out}^{KCE} < \Pi_{av.out}^k$  for  $k = \{C, KC, KE\}$ .

#### Distant RJV

**Proof of**  $\Pi_{av.out}^{KCE} < \Pi_{av.out}^k$  for  $k = \{C, KC, KE\}$

and  $\Pi^{KC} > \Pi_{av.out}^C > \Pi_{av.out}^{KE} > \Pi_{av.out}^{KCE}$

For  $\gamma \geq \hat{\gamma}_{KCE}$  we have  $\Pi^{KC} > \Pi_{av.out}^C > \Pi_{av.out}^{KE} > \Pi_{av.out}^{KCE}$ . Thus, profits of outsiders are smallest in a distant KCE,  $\Pi_{av.out}^{KCE} < \Pi_{av.out}^k$  for  $k = \{C, KC, KE\}$ .

#### D.3. Proof of Proposition 3

##### Close RJV

**Proof of**  $CS^{KCE} > CS^{KC} > CS^C > CS^{KE}$

The consumer surplus is given by  $CS^k = v - \sum_{i=1}^n [p_i D_i + \frac{t}{4} D_i^2]$  for  $k = \{C, KC, KE, KCE\}$ . Therefore we have to compare the weighted average price

$$\text{level } p^k = \sum_{i=1}^n p_i D_i$$

$$p^C = c + \frac{t}{5} - \frac{4}{25\gamma} \quad (\text{D.5})$$

$$\begin{aligned} p^{KC} &= \frac{c\gamma(898880 - 210261600\gamma t + 15931110500\gamma^2 t^2 - 425172262500\gamma^3 t^3 + 3675459453125\gamma^4 t^4)}{5\gamma(857375\gamma^2 t^2 - 49590\gamma t + 424)^2} \\ &+ \frac{-149248 + 35100352\gamma t - 2688919216\gamma^2 t^2 + 73873011180\gamma^3 t^3}{5\gamma(857375\gamma^2 t^2 - 49590\gamma t + 424)^2} \\ &+ \frac{-696630905500\gamma^4 t^4 + 735091890625\gamma^5 t^5}{5\gamma(857375\gamma^2 t^2 - 49590\gamma t + 424)^2} \end{aligned} \quad (\text{D.6})$$

$$\begin{aligned} p^{KE} &= \frac{c\gamma(281048000 - 14746850000\gamma t + 193445234375\gamma^2 t^2)}{2375\gamma(9025\gamma t - 344)^2} \\ &+ \frac{-38373888 + 2058551200\gamma t - 29078730500\gamma^2 t^2 + 38689046875\gamma^3 t^3}{2375\gamma(9025\gamma t - 344)^2} \end{aligned} \quad (\text{D.7})$$

$$\begin{aligned} p^{KCE} &= \frac{c\gamma(565592000 - 20919950000\gamma t + 193445234375\gamma^2 t^2)}{2375\gamma(9025\gamma t - 488)^2} \\ &+ \frac{-96225792 + 3731341600\gamma t - 38523573500\gamma^2 t^2 + 38689046875\gamma^3 t^3}{2375\gamma(9025\gamma t - 488)^2} \end{aligned} \quad (\text{D.8})$$

and the weighted quadratic utility loss  $\sum_{i=1}^n \frac{t}{4} D_i^2$

$$\sum D^{2C} = \frac{1}{25} \quad (\text{D.9})$$

$$\sum D^{2KC} = \frac{(147018378125\gamma^4 t^4 - 17006890500\gamma^3 t^3 + 637874004\gamma^2 t^2 - 8423840\gamma t + 36032)}{(857375\gamma^2 t^2 - 49590\gamma t + 424)^2} \quad (\text{D.10})$$

$$\sum D^{2KE} = \frac{407253125\gamma^2 t^2 - 31046000\gamma t + 594464}{25(9025\gamma t - 344)^2} \quad (\text{D.11})$$

$$\sum D^{2KCE} = \frac{407253125\gamma^2 t^2 - 44042000\gamma t + 1327136}{25(9025\gamma t - 488)^2} \quad (\text{D.12})$$

for each scenario. The lower the sum of weighted prices and utility loss the higher the consumer surplus. It is easy to show that for  $\gamma \geq \gamma_{KCE}$  we have  $CS^{KCE} > CS^{KC} > CS^C > CS^{KE}$ .

## Distant RJV



**Proof of  $CS^{KCE} > CS^C > CS^{KE} > CS^{KC}$**

For  $\gamma \geq \hat{\gamma}_{KCE}$  we have  $CS^{KCE} > CS^C > CS^{KE} > CS^{KC}$ .

#### D.4. Proof of Proposition 4

##### Close RJV

**Proof of  $W^{KCE} > W^k$  for  $k = \{C, KC, KE\}$**

and  $W^{KCE} > W^{KC} > W^C > W^{KE}$

Welfare is defined as  $W = v - c - \frac{t}{4} \sum_{i=1}^n D_i^2 + \sum_{i=1}^n D_i X_i - \frac{1}{2} \gamma \sum_{i=1}^n x_i^2$ . Therefore we have to compare the overall effective R&D investment levels weighted with the respective share of consumers  $\sum_{i=1}^n X_i^k D_i^k = 2X_{in}D_{in} + 2X_{ad}D_{ad} + X_{nonad}D_{nonad}$  for  $k = \{C, KC, KE, KCE\}$

$$\sum D X^C = \frac{4}{5\gamma} \quad (D.13)$$

$$\sum D X^{KC} = \frac{8(76449556625\gamma^4 t^4 - 8835455145\gamma^3 t^3 + 330850002\gamma^2 t^2 - 4365024\gamma t + 18656)}{5\gamma(857375\gamma^2 t^2 - 49590\gamma t + 424)^2} \quad (D.14)$$

$$\sum D X^{KE} = \frac{4/125(6532340125\gamma^2 t^2 - 500519280\gamma t + 9593472)}{19\gamma(9025\gamma t - 344)} \quad (D.15)$$

$$\sum D X^{KCE} = \frac{4/125(8584895875\gamma^2 t^2 - 901315920\gamma t + 24056448)}{19\gamma(9025\gamma t - 488)} \quad (D.16)$$

the quadratic share of consumers  $\sum_{i=1}^n D_i^{2k}$  for  $k = \{C, KC, KE, KCE\}$  is given by equation (D.9) - (D.12) and the sum of quadratic R&D expenditure

$$\sum_{i=1}^n (x_i^k)^2 = 2x_{in}^2 + 2x_{ad}^2 + x_{nonad}^2 \text{ for } k = \{C, KC, KE, KCE\}$$

$$\sum (x^C)^2 = \frac{80}{9025\gamma} \quad (D.17)$$

$$\sum (x^{KC})^2 = \frac{64(39841980472\gamma^4 t^4 - 4593815250\gamma^3 t^3 + 171825531\gamma^2 t^2 - 2265560\gamma t + 9680)}{361\gamma^2(857375\gamma^2 t^2 - 49590\gamma t + 424)^2} \quad (D.18)$$

$$\sum (x^{KE})^2 = \frac{8/625(13602254375\gamma^2 t^2 - 1063289400\gamma t + 20868624)}{361\gamma^2(9025\gamma t - 344)^2} \quad (D.19)$$

$$\sum (x^{KCE})^2 = \frac{8(1178890625\gamma^2 t^2 - 119962200\gamma t + 3463344)}{11875\gamma^2(9025\gamma t - 488)^2}. \quad (D.20)$$

$$(D.21)$$

**Proof of  $W^{KCE} > W^{KC} > W^C > W^{KE}$**

Defining the net innovative effect as  $\sum_{i=1}^n D_i X_i - \frac{t}{4} \sum_{i=1}^n D_i^2 - \frac{1}{2}\gamma \sum_{i=1}^n x_i^2$  and comparing the different forms of cooperation (C, KC, KE, KCE) it is easy to show that for  $\gamma \geq \gamma_{KCE}$  we have  $W^{KCE} > W^{KC} > W^C > W^{KE}$ .

#### Distant RJV

**Proof of  $W^{KCE} > W^k$  for  $k = \{C, KC, KE\}$**

and  $W^{KCE} > W^C > W^{KE} > W^{KC}$

For  $\gamma \geq \hat{\gamma}_{KCE}$  we have  $W^{KCE} > W^C > W^{KE} > W^{KC}$ .

#### D.5. Proof of Proposition 5

##### Close RJV

**Proof of  $W^{KCE} > W^{KC} > W^C > W^{KE}$**

see Proof of Proposition 4

##### Distant RJV

**Proof of  $W^{KCE} > W^C > W^{KE} > W^{KC}$**

see Proof of Proposition 4

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